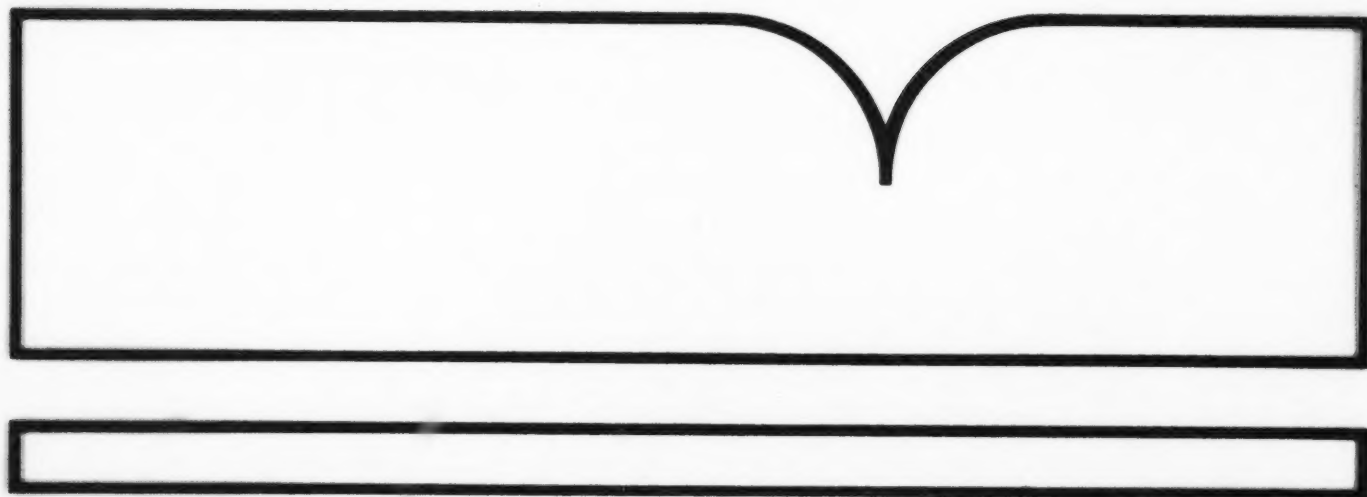


Characterization of Emissions from
Combustion Sources: Controlled Studies

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

1987



U.S. Department of Commerce
National Technical Information Service

NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)			PB88-104146	
1. REPORT NO. EPA/600/J-87/072		2.		3. RECIP
4. TITLE AND SUBTITLE Characterization of Emissions from Combustion Sources: Controlled Studies (Journal Version)			5. REPORT DATE 1987	
			6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) W. Gene Tucker			8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12.			10. PROGRAM ELEMENT NO.	
			11. CONTRACT/GRANT NO. NA (Inhouse)	
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711			13. TYPE OF REPORT AND PERIOD COVERED Journal Article; 5/85 - 2/86	
			14. SPONSORING AGENCY CODE EPA/600/13	
15. SUPPLEMENTARY NOTES AEERL project officer is W. Gene Tucker, Mail Drop 54, 919/541-2746. In Atmospheric Environment, 21:2, pp. 281-284, 2/87.				
16. ABSTRACT The paper summarizes Session I papers (given at the EPA Workshop on Characterization of Contaminant Emissions from Indoor Sources, Chapel Hill, NC, May 1985) that illustrate the progress made to date on characterizing indoor combustion emissions from unvented space heaters, gas appliances, and sidestream cigarette smoke. In the U.S., there are about 20 million gas stoves, 10 million kerosene or gas-fired unvented space heaters, 50 million gas- and oil-fired appliances and furnaces, and 20 million wood stoves and fireplaces with some potential for pollutant leakage into occupied spaces. In addition, about 600 billion cigarettes are smoked per year, perhaps 80% of them indoors. The state of knowledge of such emissions and their controllability is summarized by four general statements: (1) Unvented gas-fired appliances are important sources of indoor CO and NOx, but not of organic emissions; (2) Important combustion sources of indoor organics include smoking and maybe kerosene heaters; (3) The extent of the problem of leakage from vented appliances is simply not known; and (4) Indoor combustion sources do not appear to present major problems with controllability, if source removal is an acceptable alternative. <i>from an engineering standpoint</i> , the most challenging issue is burner design changes for unvented appliances.				
17. KEY WORDS AND DOCUMENT ANALYSIS				
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Fuel Oil	Pollution Control	13B	
Combustion	Furnaces	Stationary Sources	21B	
Gas Appliances	Wood	Indoor Air	13A	11L
Kerosene	Tobacco	Cigarettes	21D	02D
Natural Gas	Fireplaces	Particulates		
Space Heaters				
18. DISTRIBUTION STATEMENT Release to Public		19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 5	
		20. SECURITY CLASS (This page) Unclassified	22. PRICE	

EPA

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U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

CHAIRMAN'S SUMMARY, SESSION I

CHARACTERIZATION OF EMISSIONS FROM COMBUSTION SOURCES: CONTROLLED STUDIES

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Indoor sources of combustion pollutants are nearly ubiquitous. In the U.S., there are approximately 20 million gas stoves and 10 million kerosene- or gas-fired unvented space heaters. In addition, there are about 50 million gas- and oil-fired appliances and furnaces, plus 20 million wood stoves and fireplaces with some potential for pollutant leakage into occupied spaces. On top of that, some 600 billion cigarettes are smoked per year, perhaps 80% of which are smoked indoors. Taken together, these combustion sources produce a prodigious amount of gaseous and particulate pollutants.

Characterizing these sources involves measuring the pollutant emissions and the factors affecting those emissions. Measurements are made under a variety of test conditions that represent the way these combustors are operated in actual use. Such characterizations are essential for ranking their importance to indoor air pollution via modeling, for guiding the design of field surveys of indoor air quality, and for developing ways to control their emissions.

Initial studies are usually conducted in well-controlled laboratory situations, where large numbers of tests can be made cost-effectively. Studies in two- to four-room test houses can then be conducted to gain insights into pollutant dispersion rates, and interactions with other sources and 'sinks' in buildings. Generally, uncontrolled studies of sources 'in the field' are limited to buildings where there is a recognized problem with indoor air quality, and source contributions are being investigated.

Indoor combustion sources can usefully be classified by type (vented or unvented) and fuel (solid, liquid or gas). Generally, vented sources will have less polluting potential than unvented ones. Similarly, gas-fueled devices tend to burn more cleanly than liquid-fueled ones, and solid-fueled devices have the greatest potential for producing harmful products of incomplete combustion. All six combinations of combustion source and fuel types can be found indoors. In addition, sources of outdoor combustion products such as wood smoke and automobile exhaust can be strong enough in some locations to affect indoor concentrations via infiltration.

Pollutants from combustion sources can be most

simply classified into two principal categories: the traditional, inorganic combustion gases (CO, CO₂, NO, NO₂, SO₂, SO₃); and gaseous and particulate organic compounds that are products of incomplete combustion. A third category that is often overlooked covers gaseous organic compounds that evaporate from fuel being stored or transferred. Although not a product of combustion per se, these compounds result from combustion source use.

The present state of knowledge

Before judging current knowledge in any subject, it is best to state what knowledge is sought. Basically, research on characterizing sources of indoor air pollution should be aimed at answering two questions: What are the important sources? What are the most cost-effective ways to reduce their emissions?

'Importance' of sources may never be straightforward to quantify, but is undoubtedly some product of quantity of emissions, toxicity of emissions, and opportunity for exposure to the emissions. Exposures are affected by the amount of pollutant dilution and removal that occurs between the point of emission and the point of inhalation. Emissions can of course be reduced by removing a source from a building, but often a more desirable alternative will be to modify the source to reduce its emission rate. Intelligent modification of sources requires knowledge of how their emissions respond to both usage and environmental conditions. Therefore, both importance and controllability have been considered in judging our current knowledge of indoor pollution from combustion sources. The state of knowledge of emissions and their controllability is summarized in the following table. This table highlights four statements about current knowledge of sources of indoor combustion pollutants:

(1) Unvented gas-fired appliances are important sources of indoor CO and NO_x, but are not important sources of organic emissions.

(2) Important combustion sources of indoor organics include smoking and perhaps kerosene heaters (the evidence to date is mostly circumstantial; kerosene heater use can lead to oily films on indoor surfaces). Leakage of exhaust fumes from attached garages and

wood- or coal-burning stoves or fireplaces may also lead to intermittently high concentrations of health-hazardous organics. Other indoor combustion sources are unlikely to be major contributors to indoor organics.

(3) The extent of the problem of leakage from vented appliances is simply not known. Such leakage can be a major source of indoor CO, NO_x and organic products of incomplete combustion. This can happen either as back-drafting or spillage of combustion products from appliances that draw their combustion air from indoors. Back-drafting can occur when the venting system becomes blocked; is overpowered by mechanical exhaust devices such as kitchen hoods, clothes dryers, and vented ranges; or is overpowered by the 'chimney effect' of a tight building in cold and windy weather. Spillage can occur from draft hoods on gas-fired water heaters and energy-conserving furnaces with thermally controlled dampers that open slowly during furnace start-up, when emissions may contain their highest concentrations of products of incomplete combustion.

(4) Indoor combustion sources do not appear to present major problems with controllability, if source removal is an acceptable alternative. From an engineering standpoint, the most challenging issue is burner design changes for unvented appliances. However, substantially reduced emissions of both CO and NO_x, compared to emissions from present burner designs in common use, seem feasible.

Gaps in present knowledge

Many of the gaps in our understanding of indoor combustion sources can be inferred from the above

discussion of present knowledge. However, some of the gaps are more subtle. More information is needed in the areas summarized below.

(1) Usage statistics of combustion appliances are not well known.

Data are lacking on the age, condition and operational settings of appliances in use. Such data are especially important for predicting short-term concentrations of NO₂. They are also important in determining representative emission factors for organic compounds, which may be much more sensitive than the inorganic gases to non-optimum combustor operation.

(2) It is not clear that further laboratory testing of CO and NO_x emissions is needed.

The main uncertainty here stems from the fact that testing to date has been done over a very limited range of combustor age, condition and operational settings. Therefore, until a field survey of usage statistics is conducted, and existing test data are shown not to represent some major portion of combustion appliances in use, further laboratory-scale testing of CO and NO_x emission rates is not needed.

(3) Emission rates of organic compounds from indoor combustors are virtually unknown.

Even for tobacco smoking there appears to be great uncertainty, due to sampling problems with these complex emissions. The next-greatest sources of concern are kerosene heaters and wood stove leakage.

(4) Emission rates from leaking vented devices are also poorly understood.

The prevalence and causes of leakage have not been studied systematically.

(5) SO_x emissions may need more attention.

Sources of indoor combustion pollutants

Source type (fuel type)*	Importance†		Controllability
	CO, NO _x , SO _x	Organics	
<i>Unvented combustors</i>			
Stoves and space heaters (G)	H	L	H (Tuning, new burner Design)
Space heaters (K)	H	M?	M? (New burner design?)
Smoking (T)	M	H	H (Removal)
IC engines‡	M	M	H (Removal)
Candles, hobbies	L	L	H (Removal)
<i>Vented but leaking combustors</i>			
Furnances (W,C,O,G)	L?	L?	H (Draft, leak correction)
Stoves, fireplaces (W,C,G)	H?	H?	M (Draft, stove design/operation)
Water heaters (G)	L?	L?	H (Draft correction)
Clothes dryers (G)	L?	L?	H (Exhaust correction)
<i>Infiltrated pollutants from outdoor sources</i>			
Wood smoke	L	L?	H (Weatherization)
Auto exhaust	L	L?	H (Weatherization)
Industrial combustion	L	L	H (Weatherization)

* Fuel types: G—natural gas, propane, LPG; K—kerosene; T—tobacco; W—wood; C—coal; O—heating oil.

† Relative overall importance as a source of pollutant types shown: high, medium, or low. For individual buildings, the rankings could be quite different.

‡ Automobiles, lawnmowers, etc., running in attached garages.

The primary concerns here are the sulfur content in kerosene (and perhaps coal used in wood stoves), and the potential oxidation of SO_2 to SO_3 by the new catalyst-equipped kerosene heaters.

Methodological issues

For controlled studies of indoor combustion sources, the outstanding methodological issues are related to sampling and analytical methods, models, data interpretation, and consistency of units. They can be categorized into the following five areas:

(1) Research sampling methods

For unvented appliances, the hood method is probably best for obtaining data on emission rates at the source. The chamber method (including test houses) appears to be good for unreactive pollutants, but reactive surfaces for pollutant deposition may be of special concern for organics. The hood and chamber methods might be expected to give somewhat different results for condensation aerosol-type particle emissions, due to the different time/temperature conditions they present. The probe method appears most appropriate for comparing emissions from different units of the same type, or from the same units under different operating conditions, as would be done in a program to develop new burner designs. A consensus method for cigarette sidestream smoke has yet to be demonstrated; both small- and large-chamber methods have been used to date, but the quantitative effects of factors like temperature, humidity and air flow have not been published.

(2) Certification sampling methods

This is currently an issue related only to unvented appliances. The probe method may be applicable, but only if it can be shown to correlate with the hood or chamber method. If not, a standardized hood technique, developed jointly by appliance manufacturers and certification organization(s), would appear to be the method of choice.

(3) Chemical analysis methods

The basic issue here is with respect to analysis of organics. The methods of choice will have to be able to detect a broad range of products of incomplete combustion such as aldehydes, polycyclic organics and nitrated compounds, as well as aromatic components that might result from fuel evaporation (as from kerosene heaters). The indoor air research community will have to draw on the experience of others in combustion-related environmental research to ensure that appropriate techniques are used.

(4) Biological response methods

Here again the issue centers around organic emissions. Products of incomplete combustion constitute a complex mixture of pollutants. Their importance from a public health standpoint can be evaluated by risk assessment based on chemical composition, or by measurement of some biological response to the entire mixture. Biological response methods can range from short-term, bacteria-based bioassays to clinical methods where people are exposed and their physio-

logical responses measured. Only limited bioassay work has been done to date, using bacterial mutagenesis tests. Indoor air quality researchers need guidance from the health research community on which health effects from indoor organics are of primary concern, and which methods are most appropriate for measuring these effects. This is a methodological issue for non-combustion sources, as well as combustion sources.

(5) Consistent units

The indoor air research community, like other research groups, struggles with a variety of units for reporting results. As a minimum, we should use metric units and be consistent with traditional units for reporting outdoor concentrations (e.g. $\mu\text{g m}^{-3}$, except for gross pollutants like CO and CO_2 , for which parts per million is standard). The basic units for reporting data on emissions from indoor combustion sources might then be: μg for mass of pollutant; $\mu\text{g m}^{-3}$ for pollutant concentration; $\mu\text{g kJ}^{-1}$ or $\mu\text{g Kg}^{-1}$ of fuel for emission factors; kJ Kg^{-1} for fuel value; and kJ h^{-1} for fuel rate.

Research priorities

As indoor sources go, combustion sources have had a lot of attention in well-controlled research studies. This is so, however, only for the inorganic gases CO, CO_2 , NO and NO_2 , and only for unvented appliances. Even for these pollutants, there is some question whether the range of testing conditions adequately represents in-use conditions. With this overall view in mind, the following research priorities are suggested:

(1) Field surveys of combustion appliances aimed at gathering statistics on age, condition, and operational patterns.

A statistically selected but very limited number of the units could be emission-tested for NO_2 , for comparison with the existing data on NO_2 emissions from new appliances under carefully controlled conditions. Such an effort would determine if any further laboratory-based studies of NO_2 from appliances are needed.

(2) Development of an appropriate sampling method for measuring emissions of sidestream smoke, and use of the method to generate data on emission rates of particulate and gas-phase organic compounds.

Such data would help put this source into perspective relative to other combustion and non-combustion sources, for the broad range of organics being detected in buildings. An additional use of such data is to determine 'marker' or 'proxy' substances for sidestream smoke, so that its contribution to total suspended particles can be determined.

(3) Measurement of leakage rates of pollutants from vented appliances.

This could probably best be done under controlled conditions in test houses, by simulating various types of combustor and venting malfunctions.

(4) Measurement of organic emissions from kerosene heaters (new and used, properly and improperly fueled).

Exploratory testing is now being funded by EPA. SO_3 emissions from catalyst-equipped units should also be checked.

(5) Studies of cooking emissions as sources of irritant gases and particles, and possibly as sources of more toxic compounds.

Emissions from cooking, although primarily evaporative in nature, can also be the result of pyrolytic and even combustion processes. Controlled-condition studies in large chambers or test houses would be most appropriate.

(6) Studies of combustion pollutant 'sink rates' or decay, both in chambers and in well-controlled test houses.

Predicting indoor concentrations from sources emissions data is complicated not only by complex dispersion phenomena, but by removal by chemical transformations and adsorption onto airborne particles and indoor surfaces. It is essential to understand

how concentrations of combustion pollutants, especially the organic ones, are affected by these removal processes if predictive models of indoor air quality are to be used successfully.

(7) Refinement of predictive models of indoor air quality, by use of data from laboratory and test-house source characterization studies.

Predictive models are perhaps the most important tools that can be used to tie source characterization studies to field studies of indoor pollutant concentrations, exposures and effects, and put the various combustion sources into perspective as contributors to indoor air pollution.

With time, financial resources and continued dedication, the indoor air research community will be able to answer questions about the important sources of indoor combustion pollutants, and how they can best be controlled. The following papers in this session illustrate the progress made to date on characterizing unvented space heaters, gas appliances and sidestream cigarette smoke.

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